International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249–6890; ISSN (E): 2249–8001
Vol. 9, Issue 6, Dec 2019, 899–916

EXPERIMENTAL INVESTIGATION AND PROCESS PARAMETER OPTIMIZATION OF AL HYBRID COMPOSITE MATERIAL PROCESSED BY WEDM USING TAGUCHI

GOKULAKANNAN. G[1], Dr. R. V. PRAVEENA GOWDA[2] & Dr. S. RAMESH[3]

[1]*Reserch Scholar, Department of Mechanical Engineering, G Madegowda Institute of Technology, Mandya, Karnataka, India*

[2]*Principal, Department of Mechanical Engineering, The Oxford Engineering College, Bengaluru, Karnataka, India*

[3]*Department of Mechatronics, Bannari Amman Institute of Technology, Erode, Tamil Nadu, India*

ABSTRACT

Advancement of technology and numerous research work leads to the adoption of Composite material in the various sectors, like Aerospace, Automobile and Medical fields. In this research, Stir casting technique was utilized for fabricating the Hybrid Metal Matrix Composite (HMMC). Aluminium (Al6061) is used as a matrix material and the reinforcement used are Silicon Carbide (SiC) and Boron Carbide (B4C) with different weight percentages (Sic – 5, 10 and 15 percentage & B4C – 5 percentage). These fabricated composites are machined by using the Wire Cut Electrical Discharge Machine (WEDM), through which, Material Removal Rate (MRR) and Surface Roughness (Ra) has been calculated for all samples. Taguchi technique has been adopted to analyze influence of process parameters (Feed Rate, Current, Pulse on Time and Pulse off Time) and the different volumetric fraction of the reinforcement on MRR and Ra. From the developed model, it is clear that the increasing of reinforcement in the composite material had a positive impact over the MRR and Ra up to a certain extent, and later it degraded. Taguchi Optimization technique is adopted to predict the behaviors of the process parameters, and the Regression Equation was calculated for each sample to determine the MRR and Ra.

KEYWORDS: WEDM, Taguchi, Al-HMMCs, Al, SiC, B_4C & Stir Casting

Received: Aug 05, 2019; **Accepted**: Aug 25, 2019; **Published**: Nov 30, 2019; **Paper Id**.: IJMPERDDEC201976

Original Article

1. INTRODUCTION

In the fast growing economy, research is rigorously carried out to fabricate the less weight and high strength. In Aluminium (Al) centric material system, Aluminium Matrix Composites (AMCs) refers to the class of light weight and high performance [1]. The property of the AMCs can be tailored based on the addition of reinforcement in the matrix material. Intense research in the recent years provided the intrinsic and extrinsic effect of ceramic reinforcements. In this review article [2], research carried out in the last 5 years been consolidated and found that AMCs have been widely used in aerospace, automobiles and hospital industries. Strength of the composite material is decided by the ceramics property and the percentage of ceramics added to the Al material. Because of the dimensional accuracy and less distortion over the surface of the machined specimen, only non-conventional machine is used for the machining of AMCs, from which Wire Electrical Discharge Machine (WEDM) is adopted for machining of AMCs.

The Ultimate goal of the WEDM process is to attain an efficient and accurate machining operation without sacrificing the properties of the material and by well understanding of the process parameters of WEDM [3]. Wire in the WEDM

plays a major role in cutting profile accuracy, for which we have to eliminate the possibility of vibration and breakage of wire. This is attained by using the Brass as a wire material and limit the usage of reinforcement percentage in the matrix material to 30%. AMC is the new generation material with superior mechanical, physical and chemical properties when compared to other non-reinforced alloys [4]. Stir casting technique is the best processing method for fabricating of AMCs, since it is very cost effective when compared to all other processing technique [5]. In order to improve the bonding between the reinforcement and the matrix material, we need to consider influential process parameters like blade material, dimensions, heating time and temperature during the stir casting process. The rule of mixture formula is adopted for calculating the volume of reinforcement, and should be added to the matrix material based on the percentage [6] [7].

Material Removal Rate (MRR) and Surface Roughness (Ra) are the most influential output parameters during the machining of AMC in WEDM. So, in order to get the most efficient machining process, we need to maximize the MRR and minimize the Ra of the material [8], [9]. By optimizing the process parameters like Current, Feed Rate, Pulse on time, Pulse off time, Voltage, Workpiece gap to tool, Wire material, Flushing speed, Type of dielectrics. Single and Multi-objective optimization technique is used for optimizing the process parameters based on the requirement. Best machining process is calculated quantitatively by using the MRR and Ra. For single objective, Taguchi, Artificial Neural Network, Fuzzy logic and Response Surface Methodology (RSM) are used. Similarly, for multi-objective optimization technique, Grey Relational Analysis, Genetic Algorithm and Convolutional Neural Network (CNN) are used. [10]-[12].

Limited amount of research was reported in hybrid composite. Moreover, percentage of reinforcement was limited to 15%. Here in our research, we used two different reinforcement material, and increased the percentage of reinforcement to 20%. By using the Taguchi Optimization technique, we validated and proofed the obtained results.

2. MATERIAL SELECTION

Because of the lightweight, it has been widely used in the aerospace industry. Al 6061 is used as the matrix material. In our research, we selected the particulate ceramics Silicon Carbide (SiC) and Boron Carbide (B_4C) as the reinforcement material, as this ceramics was cost effective and less research has been done by using this ceramics [13], [14].

3. EXPERIMENTAL SETUP

3.1 Workpiece Preparation

Stir casting technique is implemented for fabricating the Hybrid Metal Matrix Composite (HMMCs). Four samples are prepared by varying the volume of the matrix and reinforcement materials. Due to the experimental constraints, we limited our reinforcement percentage in the matrix material to 20%. Percentage of B_4C was limited to 5%, as the usage of B_4C beyond this limit improved the brittle nature of the material. Composition of the materials are prepared based on the percentage is listed in the Table 1.

By using the rule of mixture $\rho c = \rho mVm + \rho r1Vr1 + \rho r2Vr2$, [5] the amount of reinforcement added to the matrix material is calculated. Where ρc is the density of the composite, ρm, ρr1, and ρr2 & Vm, Vr1, and Vr2 are density and volume fraction of matrix and reinforcement respectively.

Table 1: Material Composition in Volumetric Percentage

	Al6061	SiC	B_4C
Sample 1	100 % (1000g)	0	0
Sample 2	90% (900g)	5% (50g)	5% (50g)
Sample 3	85% (850g)	10% (100g)	5% (50g)
Sample 4	80% (800g)	15% (150g)	5% (50g)

Die and reinforcements are pre-heated in the furnace for 500 and 600°C for three hours respectively. Al 6061 was melted in the crucible, and then preheated reinforcement is poured into the matrix material. In order to improve the wettability of the matrix and reinforcement material, 1% of the matrix and reinforcement material is added. Motorized Stirrer was placed at 1/4th the height of the crucible and stirred @ 400 Rpm for 15 min [9].

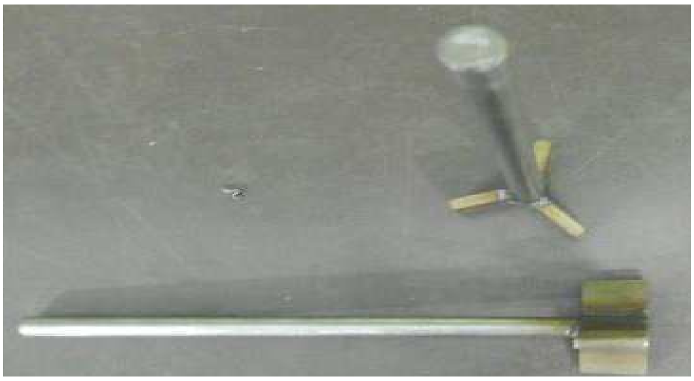


Figure 1: Stirrer used in the Casting Process.

The stirrer is made up of brass (blades of the stirrer) material welded against the stainless steel (rod). For proper mixing of the reinforcement, we designed the stirrer blades in such a way that Length of rod = 300mm, Diameter of rod = 10mm, blade length = 20mm x 20mm, three brass blades are placed at 120° angle to the stainless steel rod. Later, molten material was poured in the preheated die. In order to study the distribution of reinforcement in the matrix material, microstructure image of the specimen is required, for which we have to prepare the specimen.

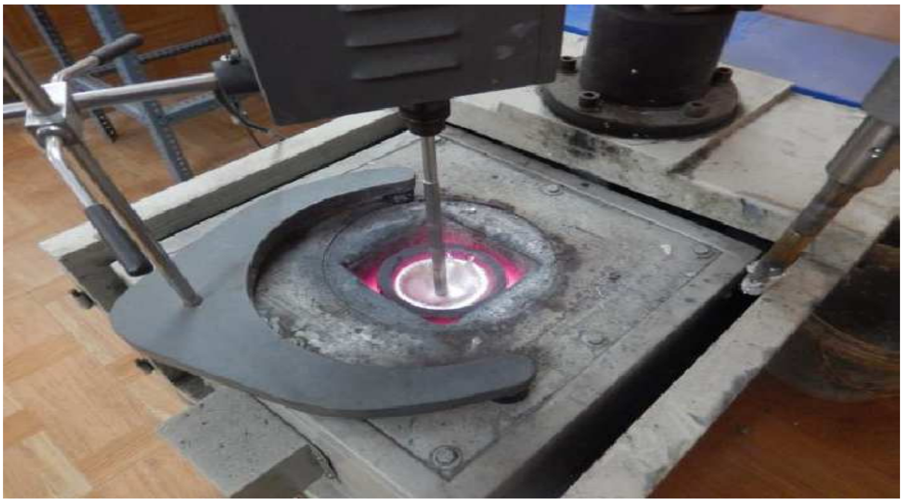


Figure 2: Stir Casting.

After the small piece of specimen is moulded (by using bakelite powder), we have to polish the moulded specimen by using the Emery sheet of following grade – 120, 220, 320, 400, 600, 800, 1000. At last, we needed to polish the specimen using the Alumina Disc Polishing, which will enhance the structure of the materials, while visualizing in Microscope.

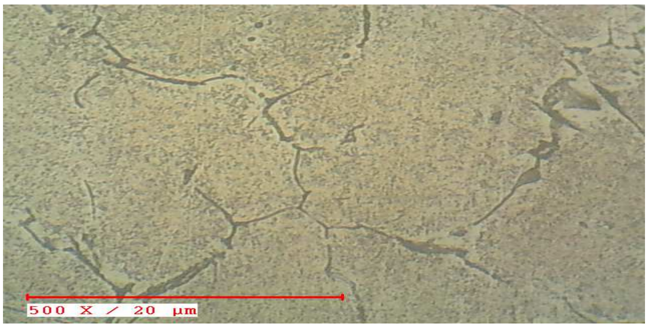


Figure 3: Microstructure Image of Sample 1.

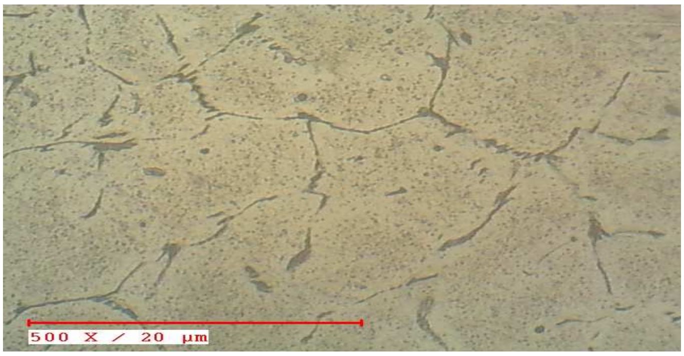


Figure 4: Microstructure Image of Sample 2.

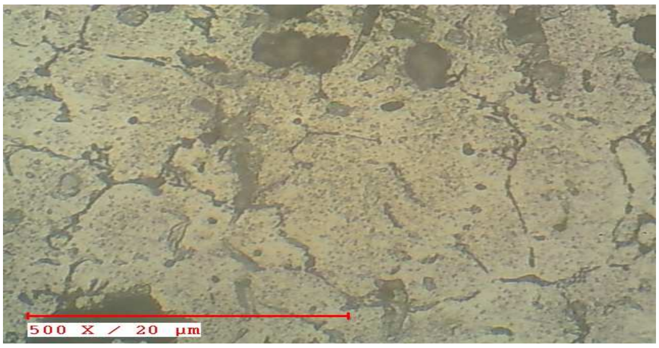


Figure 5: Microstrucutre Image of Sample 3.

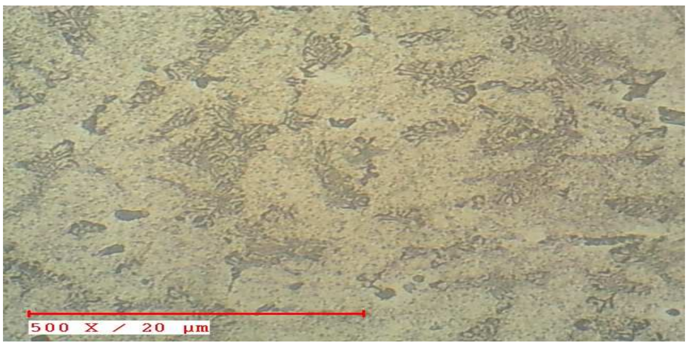


Figure 6: Microstructure Image of Sample 4.

Figure 3 to Figure 6 shows that the reinforcements are equally distributed over the matrix material. Also, we are able to see some of the craters and porosity in the microstructure image. Room temperature and time taken to pour the

molten material in the cast plays major role in the crater and the porosity formation in the prepared specimen. As the percentage of reinforcement increases, there is a chance of increase of porosity and carter in the material.

3.2 Machining Process

Fabricated HMMCs are machined by using computer aided automatic fuzzy controlled CNC three axis WEDM, as shown in figure 8. In WEDM, machining performance is measured by using the MRR, Ra and Recast layer thickness. They are dependent upon the process parameters like Feed Rate, Voltage, Current, Pulse On time, Pulse Off time, Dielectric liquid, Machining wire, Spark gap. The objective of the research is to maximize the MRR and minimize the Ra. In order to achieve this, we need to alter the process parameters. However, it is not practically possible to alter all process parameters to find out the best-optimized process parameters, and only experienced machine operator might achieve this. This issue has been resolved by adopting the statistically designed experiment to study the influence of the process parameters over the output response of the material.

Table 1: WEDM Machining Parameters

	Material	**Brass**
Wire Tool	**Wire Diameter**	0.24mm
	Orientation	Vertical
Dielectric	**Medium**	Deionized water mixed with paste
Workpiece	**Material**	Aluminium 6061
	Compostion	Sample 1: Al (100%) +SiC (0%) + B_4C (0%)
		Sample 2: Al (90%) +SiC (5%) + B_4C (5%)
		Sample 3: Al (85%) +SiC (10%) + B_4C (5%)
		Sample 4: Al (80%) +SiC (15%) + B_4C (5%)

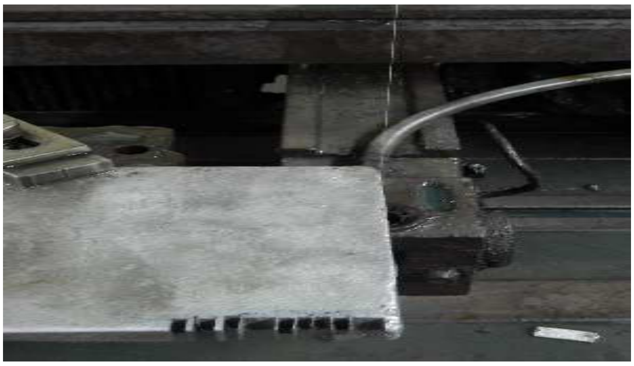


Figure 7: Workpiece, Cutting Wire and Dielectric Nozzle.

Figure 8: WEDM Machine Setup.

Table 2: Process Parameters and the Levels

Machining Parameters	Units	Symbols	Level 1	Level 2	Level 3
Feed Rate	mm/min	F	50	75	100
Current	amps	Ip	2	3	4
Pulse on Time	µs	Ton	31	32	33
Pulse Off Time	µs	Toff	5	6	7

4. DESIGN OF EXPERIMENT BASED ON TAGUCHI METHOD

In our research, most widely used and universally recognized Taguchi method is used for designing the level of experiments based on the process and response parameters. The Process parameters and the levels listed in the Table III are selected based on some prelimenary investigations like trail run, literature survey and the experience. Response parameters analysed in this research are MRR and Ra, and thus MRR was calculated based on (1) and Ra was measured by using the surface roughness machine – DektakXT Stylus Profilometer. For the four process parameters and two response parameters, based on Taguchi Design of Experiment (DOE), L9 array was adopted and listed in the Table 4. Spark gap maintained between the wire and the workspace is 0.18mm.

Table 3: Design of Process Parameters(L9)

L9 Design of Experiment				Experimental Trials for L9			
F	Ip	Ton	Toff	F	Ip	Ton	Toff
1	1	1	1	50	2	31	5
1	2	2	2	50	3	32	6
1	3	3	3	50	4	33	7
2	1	2	3	75	2	32	7
2	2	3	1	75	3	33	5
2	3	1	2	75	4	31	6
3	1	3	2	100	2	33	6
3	2	1	3	100	3	31	7
3	3	2	1	100	4	32	5

Table 4: Experimental Design and Result using Orthogonal Array(L9)

Feed Rate (F)	Current (Ip)	Pulse on Time (Ton)	Pulse Off Time (Toff)	Sample 1		Sample 2		Sample 3		Sample 4	
				MRR	Ra	MRR	Ra	MRR	Ra	MRR	Ra
50	2	31	5	43.48	3.91	41.20	4.08	36.00	4.44	26.42	4.99
50	3	32	6	46.58	4.01	42.50	4.18	39.23	4.62	30.02	5.37
50	4	33	7	47.28	4.12	44.44	4.34	42.13	4.96	35.91	5.39
75	2	32	7	47.90	4.21	44.25	4.45	29.88	5.14	33.04	5.37
75	3	33	5	60.48	4.42	56.35	4.64	48.70	5.62	43.66	5.77
75	4	31	6	59.76	4.31	44.06	4.55	49.18	5.57	39.66	5.83
100	2	33	6	48.55	4.91	46.78	5.12	35.55	6.21	38.86	6.67
100	3	31	7	58.22	4.79	43.99	4.98	37.22	6.31	35.31	6.43
100	4	32	5	64.10	5.26	59.20	5.41	59.00	6.65	48.22	7.25

$$\mathrm{MRR} = \frac{(2W_g + D).t.L}{T} \tag{1}$$

where,

Wg = spark gap (0.18 mm)

D = diameter of wire (0.24 mm)

T = thickness of the work piece (10 mm)

L = distance travelled by tool (25 mm)

T = time taken for cut one profile (minutes)

The Specimen of size 100x100x10 mm, was machined into the size of 10x5x10 mm in WEDM machine. For high MRR and good Surface finish, reusable and less breakage, brass wire is used. Diameter of the brass wire is 0.24mm. All four samples are machined by WEDM and MRR & Ra was calculated , as shown in table V.

5. DATA ANALYSIS

5.1 Taguchi Analysis Method

The Signal to Noise ratio S/N was calculated for the experimental results of MRR and Ra for all four samples (different composition of reinforcement) in the Table VI. Usually S/N ratio is used to determine the individual consequence of process parameter over the response parameter for level of factor. In Taguchi design, there are three options to calculate the S/N ratio – Larger is better (LB), Nominal is best (NB), Smaller is best. In our research, we have objective to improve the MRR and reduce the Ra, so the formula for calculating the S/N ratio is mentioned in (2) & (3) respectively; in which Y_{MRR} and Y_{Ra} are the response of MRR and Ra respectively. Number of trails are represented as n. The S/N ratio for all the samples are listed in the Table VI & Table VII.

The Analysis of Variance (ANOVA) is executed to determine the Null Hypothesis (Ho) for the experimental data with the confidence level of 95% and the pure-error PE at less than 5%. We need to determine the inferential relation between the process parameters and the response variable for eliminating the Ho and calculating the SN ratio.

$$\mathrm{S/N(HB)} = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{{Y_{MRR}}^2}\right) DB \quad (2)$$

$$\mathrm{S/N\ (LB)} = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{{Y_{Ra}}^2}\right) \mathrm{DB} \quad (3)$$

Table 5: S/N Value for Experimental Value of Sample 1 and Sample 2

Trails	Sample 1 (Al (100%))				Sample 2 (Al (90%) +SiC (5%) + B_4C (5%))			
	Experimental Value		S/N Ratio		Experimental Value		S/N Ratio	
	MRR	Ra	MRR	Ra	MRR	Ra	MRR	Ra
1	43.48	3.91	32.7654	-11.8435	41.20	4.08	32.2979	-12.2132
2	46.58	3.91	33.3647	-11.8435	42.50	4.08	32.5678	-12.2132
3	47.28	4.01	33.4935	-12.0629	44.44	4.18	32.9554	-12.4235
4	51.90	4.12	34.3033	-12.2979	44.25	4.34	32.9176	-12.7585
5	60.48	4.21	35.6328	-12.4856	56.35	4.45	35.0179	-12.9705
6	59.76	4.42	35.5284	-12.9084	44.06	4.64	32.8799	-13.3272
7	60.23	4.31	35.5963	-12.6895	46.78	4.55	33.4017	-13.1666
8	58.22	4.91	35.3014	-13.8228	43.99	5.12	32.8667	-14.1825
9	64.10	4.79	36.1375	-13.6067	59.20	4.98	35.4464	-13.9481

Table 6: S/N Value for Experimental Value of Sample 3 and Sample 4

Trails	Sample 3 (Al (90%) +SiC (10%) + B_4C (5%))				Sample 4 (Al (85%) +SiC (15%) + B_4C (5%))			
	Experimental Value		S/N Ratio		Experimental Value		S/N Ratio	
	MRR	Ra	MRR	Ra	MRR	Ra	MRR	Ra
1	36.00	4.44	31.1261	-12.9470	26.42	4.99	28.4387	-13.9609
2	39.23	4.44	31.8718	-12.9470	30.02	4.99	29.5482	-13.9609
3	42.13	4.62	32.4928	-13.2853	35.91	5.37	31.1044	-14.5984
4	29.88	4.96	29.5078	-13.9096	33.04	5.39	30.3807	-14.6318
5	48.70	5.14	33.7508	-14.2221	43.66	5.37	32.8017	-14.6016
6	49.18	5.62	33.8358	-14.9983	39.66	5.77	31.9671	-15.2306
7	35.55	5.57	31.0156	-14.9098	38.86	5.83	31.7889	-15.3159
8	37.22	6.21	31.4157	-15.8606	35.31	6.67	30.9588	-16.4877
9	59.00	6.31	35.4170	-16.0033	48.22	6.43	33.6645	-16.1669

From the detail analysis of the response parameters like MRR and Ra against the process parameters, it is evident that the response values has differed across all samples, but the relationship between the process and response parameters are similar across all samples. This hypothesis was validated and confirmed by the result obtained from the Taguchi analysis. The S/N graph from MINITAB 18 indicates the process parameters like Pulse on Time, Discharge Current and Feed Rate have adverse impact over the response parameters like MRR and Ra. The optimum level of process parameter for MRR and Ra is determined by using the following Equation (4).

$$\mu_{opt} = \mu_{total} \sum_{i=1}^{n}(\mu_i - \mu_{total}) \tag{4}$$

where,

μ_{opt} = Optimum Value.

μ_{total} = Total mean of S/N ratio

μ_i = Mean S/N ratio

n = Number of process parameters.

The Optimum level of Process parameter for MRR was selected based on the higher value of S/N ratio from all samples. Process parameter combination of F_3, Ip_3, Ton_2 and $Toff_3$, across all samples following the parameters shows linear relationship, hence optimum S/N ratio for maximum MRR can be estimated by (5).

$$\mu_{opt} = \mu_{total} + (\mu_{F3} - \mu_{total}) + (\mu_{Ip3} - \mu_{total}) + (\mu_{Ton2} - \mu_{total}) + (\mu_{Toff3} - \mu_{total}) \tag{5}$$

Similarly, optimum levels of process parameters for minimum value of Ra are calculated by using the following (6), by using the combination of process parameters F_1, Ip_1, Ton1 and $Toff_3$. For all samples, the relation between the process parameters and Ra are similar.

$$\mu_{opt} = \mu_{total} + (\mu_{F1} - \mu_{total}) + (\mu_{Ip1} - \mu_{total}) + (\mu_{Ton1} - \mu_{total}) + (\mu_{Toff3} - \mu_{total}) \tag{6}$$

The S/N ratio curve and mean value for both MRR and Ra have been determined by using the MINITAB for all four samples. From the graph of S/N ratio curve for MRR and Ra in all four samples, it is evident that the linear relation

between the process parameters and MRR are similar across all levels despite of the sample. Considering the constraint of this article, we considered the S/N ratio curve for MRR and Ra for four samples. It is shown in the Fig. 9 and Fig.10 respectively.

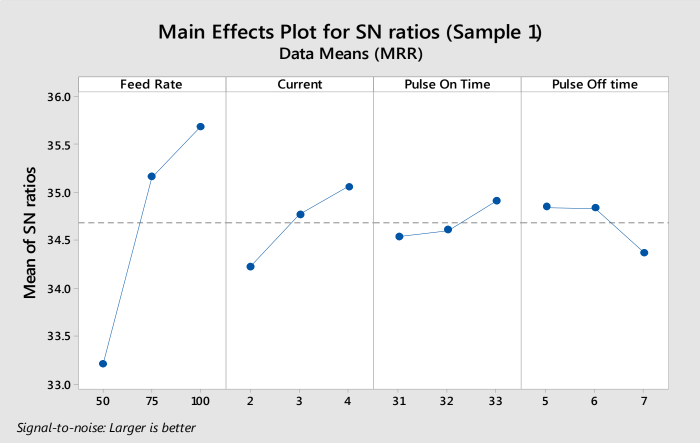


Figure 9: S/N Ratio Curve for Sample 1 – MRR.

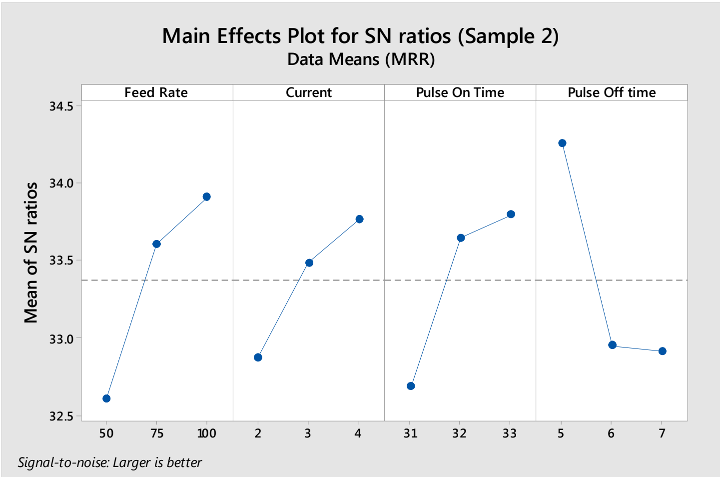


Figure 10: S/N Ratio Curve for Sample 2 – MRR.

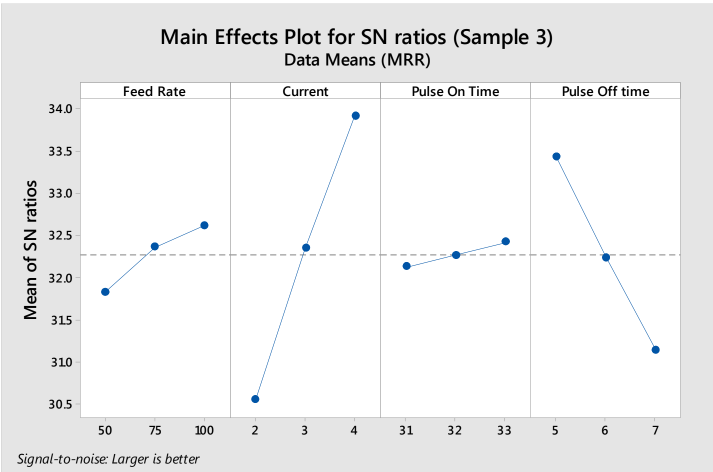


Figure 11: S/N Ratio Curve for Sample 3 – MRR.

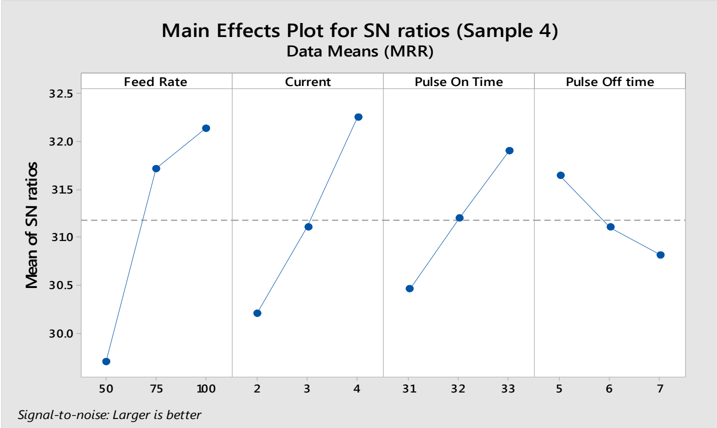


Figure 12: S/N Ratio Curve for Sample 4 – MRR.

Form the above graph, it is observed clearly that out of four process parameters, Feed Rate, Current and Pulse on Time have a positive impact over the MRR, and Pulse off Time has negative impact. Our goal is to optimize the MRR – meaning, it is larger the better. Invariantly, we need to increase the feed rate, Current and Pulse on Time to get the maximum MRR. For all four samples, despite of the percentage of reinforcement in the matrix material, the relation between the process parameters and the MRR is similar. It means that in order to attain the high MRR, irrespective of the percentage of reinforcement in matrix material, there is a need to increase feed rate, current and pulse on time, and decrease the pusle off time.

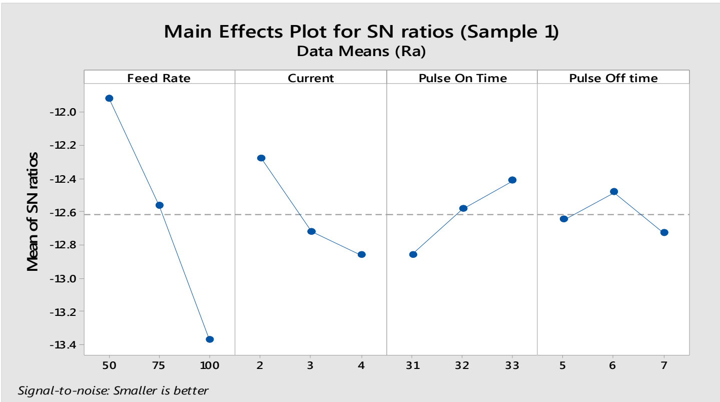


Figure 13: S/N Ratio Curve for Sample 1 – Ra.

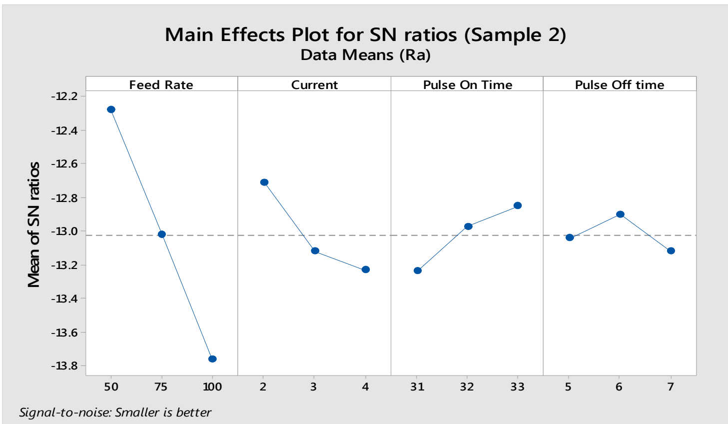


Figure 14: S/N Ratio Curve for Sample 2 – Ra.

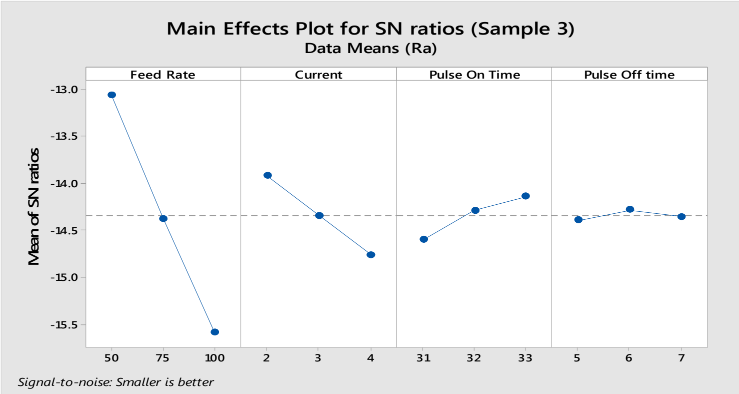


Figure 15: S/N Ratio Curve for Sample 3 – Ra.

Figure 13 to Figure 16 represents the S/N ratio for all Samples from 1 to 4 and influence of Input process parameters like Feed Rate, Current, Pulse on Time and Pulse off Time over the Ra of the machiend surface. Smaller the Better is considerd while calcualting the S/N ratio. Our objective is to decrease the value of the Ra (good surface finish having least value of Ra); it is attained by decreasing the feed rate, current and pulse on time. Subsequently, Pulse off Time should be maintained at level 2 instead of level 1 and level 3; rest of the parameters can maintain at level 1. Except pulse off time, rest of the parameters are proportional to Ra value.

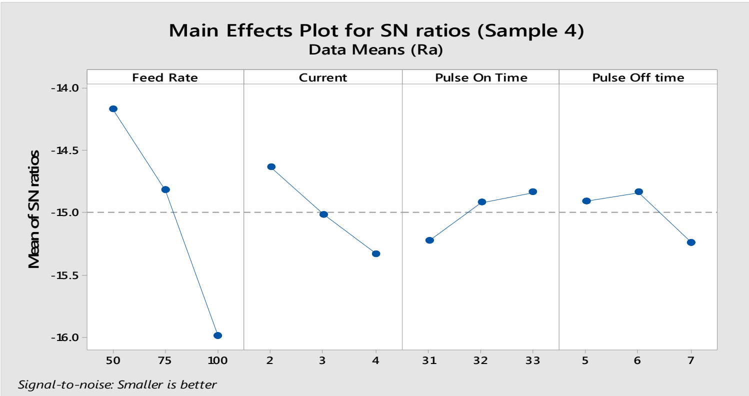


Figure 16: S/N Ratio Curve for Sample 4 – Ra.

5.2 Regression Model for Ra and MRR for all Samples

The relation between the input variable and the output response variable is determined by using the regression model. There are four types of regression models.- They are linear, non-linear, exponential and power. A huge amount of research was carried out in developing regression model to find out which model is the best. The high co-efficient of determinants (R^2) is used to select the best regression model. When compared to other models, non-linear regression model (R^2 >99%) is good. The regression equation for the calculation of the MRR and Ra is given in the Table VIII and Table IX respectively. The regression equations are calculated by using MNITAB software.

Table 7: Regression Equation for MRR

Regression Equation for Calculating MRR	
Sample 1	0.1 +0.3014 Feed Rate +2.59 Current + 1.09 Pulse on Time - 1.78 Pulse Off time
Sample 2	-45.4 +0.1455 Feed Rate +2.58 Current + 3.05 Pulse on Time - 4.01 Pulse Off time
Sample 3	23.5 +0.0960 Feed Rate +8.148 Current +0.663 Pulse on Time -5.744 Pulse Off time
Sample 4	-67.8 +0.2003 Feed Rate +4.246 Current +2.839 Pulse on Time -2.339 Pulse Off time

Table 8: Regression Equation for Ra

Regression Equation for Calculating the Ra	
Sample 1	6.42 + 0.01454 Feed Rate + 0.1467 Current - 0.1184 Pulse on Time+ 0.0218 Pulse Off time
Sample 2	6.27 + 0.01542 Feed Rate + 0.1371 Current - 0.1086 Pulse on Time+ 0.0215 Pulse Off time
Sample 3	7.333 + 0.030607 Feed Rate + 0.2642 Current - 0.1580 Pulse on Time- 0.0180 Pulse Off time
Sample 4	7.15 + 0.02393 Feed Rate + 0.2275 Current - 0.1443 Pulse on Time+ 0.1068 Pulse Off time

6. RESULTS AND DISCUSSIONS

6.1 Experimental value of MRR and Ra

From the Experimental result, we can conclude that the process parameters like feed rate, current, pulse on time and pulse off time have significant influence in linear manner over the output response, irrespective of the sample. Experimental values of MRR and Ra against the sample are shown in the Figure 17 and Figure 18.

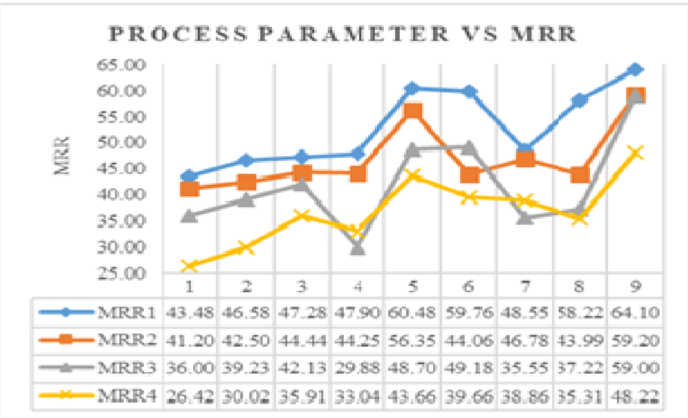


Figure 17: Experimental Value of MRR for Four Samples.

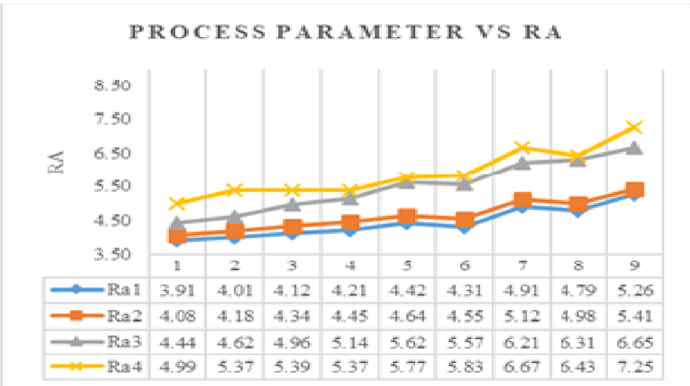


Figure 18: Experimental Value of MRR for Four Samples.

MRR and Ra been calculated and it was validated against the specimen. Our objective of the work is to increase the MRR and decrease the value of Ra. From the overall value, it is clear that MRR is inversely proportional to the percentage of reinforcement in the matrix material. Because ceramics are very hard material, WEDM took much time to machine the material with having reinforcement rather than the pure alloy; although the process parameters influence the output response MRR. From the overall observation of the experimental value, it is evident, that Pure Al alloy exhibit good MRR when machining with WEDM. As the percentage of reinforcement in the Matrix material increases, MRR also decreases.

WEDM always aim for producing good-machined surface. This parameter was evaluated by using the Ra value. Our objective is to decrease the value of Ra, from the overall experimental result; it is clear, pure Al alloy having good surface finish rather than the reinforced Al. Ceramics having high hardness value, while calculating the Ra value, microstructure of the ceramics in the Al material shows lot of peaks.

6.2 Analytical Response of MRR and Ra

Our ultimate aim is to optimize the process parameters of all four samples so as to get maximum MRR and minimum Ra. Experimental result shows the high-level relationship between the MRR and Ra to the sample. In order to obtain the detailed influence of process parameter over the MRR and Ra and to figure out the exact optimized set of parameters, we adopted Taguchi Analysis of Variance (ANOVA). Influence of each process parameter in the output response is given in the Table X for MRR and Table XI for Ra. When feed rate, current and pulse on time is on level 3, we can attain maximum MRR for all samples. Since, each sample had significant parameter that influenced the MRR and Ra; it was decided based on the P-Value. Hence, we can conclude Feed rate is the most influential parameter on MRR (Higher the better) and Ra (Smaller the better). If the feed rate is increased, the wire is travelled with high velocity over the workpiece, so the ionization zone formation is too quick and its leads to quick machining of material. Likewise, in order to get good surface finish, we need to decrease the feed rate and increase the pulse off time.

From the Taguchi analysis method, optimized set of process parameter is determined. For MRR – to have high removal rate, we need to adopt the process parameters - Feed rate – 100, Current – 4, pulse on time – 32 and the pulse off time – 5, since all the sample utilizing the same set of optimized parameter to obtain high MRR. For Ra – less surface roughness, the optimized set of process parameters are Feed rate – 50, current – 2, pulse on time – 31 and pulse off time – 5. The influence of pulse off time over the MRR and Ra is greatly influenced by feed rate and current. Each sample had different optimized MRR and Ra value, but the relation between the process parameters and output response are similar across all sample

Table 9: ANOVA Value for MRR

Analysis of Variance (MRR)						
Sample 1	**Source**	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
	Regression	4	406.961	101.74	10.66	0.021
	Feed Rate	1	340.664	340.664	35.7	0.004
	Current	1	40.224	40.224	4.21	0.109
	Pulse On Time	1	7.117	7.117	0.75	0.437
	Pulse Off time	1	18.956	18.956	1.99	0.232
	Error	4	38.173	9.543		
	Total	**8**	**445.134**			
Sample 2	**Source**	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
	Regression	4	271.9	67.97	5.42	0.065
	Feed Rate	1	79.43	79.43	6.33	0.066
	Current	1	39.86	39.86	3.18	0.149
	Pulse On Time	1	55.99	55.99	4.46	0.102
	Pulse Off time	1	96.61	96.61	7.7	0.05
	Error	4	50.18	12.54		
	Total	**8**	**322.07**			
Sample 3	**Source**	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
	Regression	4	633.557	158.389	92.29	0
	Feed Rate	1	34.576	34.576	20.15	0.011

	Current	1	398.366	398.366	232.13	0
	Pulse On Time	1	2.64	2.64	1.54	0.283
	Pulse Off time	1	197.974	197.974	115.36	0
	Error	4	6.865	1.716		
	Total	**8**	**640.422**			
Sample 4	**Source**	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
	Regression	4	339.74	84.934	16.18	0.01
	Feed Rate	1	150.38	150.383	28.65	0.006
	Current	1	108.17	108.167	20.61	0.011
	Pulse On Time	1	48.35	48.347	9.21	0.039
	Pulse Off time	1	32.84	32.838	6.26	0.067
	Error	4	21	5.249		
	Total	**8**	**360.73**			

Table 10: ANOVA Value for Ra

Analysis of Variance (Ra)						
Sample 1	**Source**	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
	Regression	4	1.00864	0.25216	21.76	0.006
	Feed Rate	1	0.79255	0.792551	68.4	0.001
	Current	1	0.12907	0.129067	11.14	0.029
	Pulse On Time	1	0.08417	0.084175	7.26	0.054
	Pulse Off time	1	0.00285	0.002846	0.25	0.646
	Error	4	0.04635	0.011587		
	Total	**8**	**1.05499**			
Sample 2	**Source**	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
	Regression	4	1.07849	0.269622	27.44	0.004
	Feed Rate	1	0.89215	0.89215	90.8	0.001
	Current	1	0.1128	0.112797	11.48	0.028
	Pulse On Time	1	0.07077	0.070771	7.2	0.055
	Pulse Off time	1	0.00277	0.002772	0.28	0.623
	Error	4	0.0393	0.009825		
	Total	**8**	**1.11779**			
Sample 3	**Source**	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
	Regression	4	4.08368	1.02092	318.31	0
	Feed Rate	1	3.51303	3.51303	1095.31	0
	Current	1	0.41888	0.41888	130.6	0
	Pulse On Time	1	0.14982	0.14982	46.71	0.002
	Pulse Off time	1	0.00195	0.00195	0.61	0.479
	Error	4	0.01283	0.00321		
	Total	**8**	**4.09651**			
Sample 4	**Source**	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
	Regression	4	2.65149	0.66287	17.21	0.009
	Feed Rate	1	2.14762	2.14762	55.76	0.002
	Current	1	0.31056	0.31056	8.06	0.047
	Pulse On Time	1	0.12491	0.12491	3.24	0.146
	Pulse Off time	1	0.06841	0.06841	1.78	0.253
	Error	4	0.15407	0.03852		
	Total	**8**	**2.80556**			

7. CONCLUSIONS

- Al- AMC of four different samples was fabricated successfully by using the stir casting technique.
- Optical microscope image shows that reinforcement was equally distributed over the matrix material; crater and

porosity is observed for the specimen having 15 and 20% reinforcement.

- Widely used Non-traditional machining process, WEDM is adopted to machine the fabricated Al composite of different percentage of reinforcement.
- Significant influence of process parameters like feed rate, current, pulse on time and pulse off time over the MRR and Ra was determined by using the Taguchi analysis method.
- Regression equation was formulated to calculate the optimized value of MRR and Ra for all samples, since each sample has different composition volume, and so regression equation also differs.
- The relationship between the process parameters and output response is varied linearly from pure Al alloy to Al composite having 20% of reinforcement.
- Optimized set of process parameters is determined by using Taguchi for high MRR and low Ra value.

REFERENCES

1. *M. K. Surappa, "Aluminium matrix composites : Challenges and opportunities," Sadhana - Acad. Proc. Eng. Sci., vol. 28, no. April, pp. 319–334, 2003.*
2. *G. Gokulakannan, R. Praveena Gowda, and S. Ramesh, "Machining of Aluminium Hybrid metal Mtrix Composite by Wire Electrical Discharge Machine: A Review," IUP J. Mech. Eng., vol. IX, no. 4, pp. 46–64, 2016.*
3. *K. Ho, S. Newman, S. Rahimifard, and R. Allen, "State of the art in wire electrical discharge machining (WEDM)," Int. J. Mach. Tools Manuf., vol. 44, no. 12–13, pp. 1247–1259, Oct. 2004.*
4. *V. K. Saini, Z. A. Khan, and A. N. Siddiquee, "Advancements in Non-Conventional Machining of Aluminum Metal Matrix Composite materials," Int. J. Eng. Res. Technol., vol. 1, no. 3, pp. 1–14, 2012.*
5. *Verma, S., & Rao, P. S. Design and Analysis of Process Parameters on Multistage Wire Drawing Process-A Review.*
6. *J. Hashim, L. Looney, and M. S. J. Hashmi, "Metal matrix composites : production by the stir casting method," J. Mater. Process. Technol., vol. 93, pp. 1–7, 1999.*
7. *C. Velmurugan, R. Subramanian, S. Thirugnanam, and B. Ananadavel, "Experimental investigations on machining characteristics of Al 6061 hybrid metal matrix composites processed by electrical discharge machining," Int. J. Eng. Sci. Technol., vol. 3, no. 8, pp. 87–101, 2011.*
8. *A. R. Ahamed, P. Asokan, and S. Aravindan, "EDM of hybrid Al–SiCp–B4Cp and Al–SiCp–Glassp MMCs," Int. J. Adv. Manuf. Technol., vol. 44, no. 5–6, pp. 520–528, Feb. 2009.*
9. *Shrivastava, D., & Richhariya, V. Analytical survey on various image enhancement techniques for various parameters.*
10. *S. Ramesh, N. Natarajan, and V. Krishnaraj, "Experimental investigation of Al6061 / SiC p / B 4 C p hybrid MMCs in wire electrical discharge machine," indian J. Eng. &materials Sci., vol. 21, no. August, pp. 409–417, 2014.*
11. *S. Ramesh, G. Gokulakannan, N. Natarajan, and V. Krishnaraj, "Investigation of Thermal damage layer in WEDM of Hybrid Metal Matrix Composites," Int. J. Appl. Eng. Res., vol. 10, no. 38, pp. 29321–29326, 2015.*
12. *N. Muthukrishnan and J. P. Davim, "Optimization of machining parameters of Al/SiC-MMC with ANOVA and ANN analysis," J. Mater. Process. Technol., vol. 209, no. 1, pp. 225–232, 2009.*

13. BA, E., EO, A., AL, A., & PS, O. Effect of Antidepressant Treatment on Haematological Parameters of Depressive Disordered Patients in a Nigerian Teaching Hospital.

14. S. Murugesan, K. Balamurugan, C. sathiya narayanan, and p G. Venkatakrishnan, "Study on EDM of Al-15 % SiC MMC using Solid and Multihole Electrodes- A Taguchi Approach," Eur. J. Sci. Res., vol. 68, no. 2, pp. 161–171, 2012.

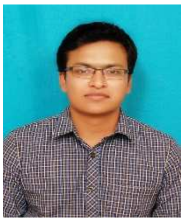
15. S. Boopathi and K. Sivakumar, "Experimental investigation and parameter optimization of near-dry wire-cut electrical discharge machining using multi-objective evolutionary algorithm," Int. J. Adv. Manuf. Technol., 2012.

16. Ejiofor, O. S., Abuchi, N. C., & Chukwuemeka, A. (2014). Loss Estimation and Parameters Calculation of A 7.5 kW Induction Machine. International Journal of Electrical and Electronics Engineering (IJEEE), 3(4), 31–36.

17. S. Ramesh, G. Gokulakannan, N. Natarajan, and V. Krishnaraj, "Analysis of temperature distribution in wire electrical discharge machine on hybrid Al-MMCs," indian J. Eng. &materials Sci., vol. 25, no. August, pp. 301–306, 2018.

18. S. Ramesh, N. Natarajan, V. Krishnaraj, and G. Gokulakannan, "Determination of cutting operation number for multipass cutting in WEDM of composite materials," Int. J. Appl. Eng. Res., vol. 9, no. 24, pp. 27041–27051, 2014.

AUTHORS PROFILE



Gokulakannan. G completed his Masters in Engineering Design with impeccable academic records in Bannari Amman Institute of technology and currently pursuing Ph.D in VTU. His Current area of research mainly focused on Hybrid Composite materials machining (Unconventional Machining), modelling and analysing (ANSYS), In order to reduce the real time practical experiment. In this field, author have indigenous six publication in various reputed international Journals. Apart from the above research, author is working on Rapid Prototyping (3D modelling) and Deep Learning. Author been actively participating in various Hackathon related to Deep learning and Machine learning. He won various awards in terms of his best work and management activities, like best start performer award. he also been actively working on optimization of the SEM image using the Deep Learning models.

Dr R V Praveena Gowda is the Principal of G Madegowda Institute of Technology, with 24 years of Administrative, research and teaching experience. Prior to this he was the Principal at The Oxford College of Engineering & prof at DSATM heading the mechanical Department. He has obtained Ph.D. in Mechanical Engineering specialized in Product Design and Development. He has won many awards including the Young Scientist Gold medal award by International consortium of Contemporary Biologists, for his contributions. He has published 100 + technical papers & amp; publications. He is also currently guiding 3 research scholars to gain their PhD.3E – Educate, Empower, Enable is his

leadership Mantra. He empowers his staff & amp; ensures effective deliberation of academic activities. He believes in creating a conducive environment to meet &exceed all goals. Encourages new ideas to improve excellence in teaching, coaching, learning & inquisitive research activities. He encourages straight forwardness, honestly & integrity. He aims at developing Industry Ready Professionals by educating well instead of training. A well-established Communication system ensure great progress in any organisation.

Dr S Ramesh been awarded Ph.D. by in the year of 2015. He having 7 years of academic experience and 6 years of Industrial experience. Author is specialized in composite materials, robotics and automation. Because of his deep experience in Industry, his area of research always focused on automation and consumer benefits products. Author received fund from ISTE-SRM University and ISTE of 1 lakh and 5000 respectively. He holding the research publications in 12 journals. He handling various subjects in the academic side include Engineering Materials and Metallurgy, Production Planning and Control and Design of Hydraulic and Pneumatic system. Under his guidance lot of innovative project been completed be various Undergraduate and post graduate students. Because of his constant contribution to the research, he actively organizing various International conference for research scholars.